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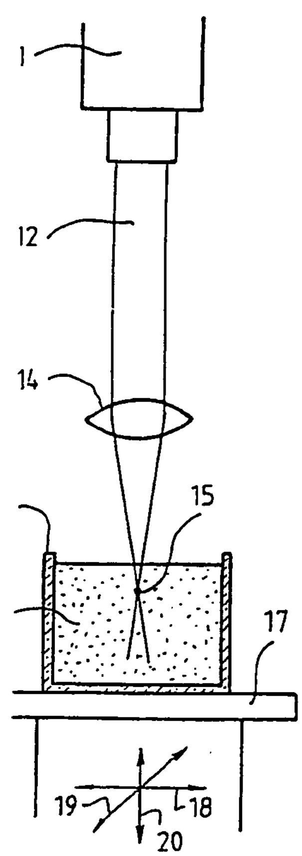
(54) Title: OPTICAL WAVEGUIDES

(57) Abstract

In the production of an optical waveguide a light beam (12) from a high power laser (11) is focussed by lens (14) into a concentrated energy zone (15) in a body (16) of polymerisable material to cause photo-initiated polymerisation of that material. The concentrated energy zone (15) is caused to move in a path through the body (16) to produce a strand of polymerised material along the path, which strand is of higher refractive index than the surrounding body of material and is capable of acting as an optic waveguide for transmission of light along the strand. An optic waveguide device can be fabricated for forming a plurality of waveguide strands in a single body of polymerisable material.



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OPTICAL WAVE GUIDES

TECHNICAL FIELD

This invention relates to the field of optical wave guides.

Optical wave guides may be used for making optical interconnections between points in space, for example between separated optical components in an optical system or between optical and opto-electronic components on integrated circuit chips.

In the known art, such optical interconnects have been made holographically, by using micro-lenses or by bulk "plumbing" with fibres and fibre couplers or other components requiring careful assembly and interconnection of the various components. The construction of wave guide devices using such current technology is difficult and is an area in need of improvement, particularly for applications in high speed data communication and for optical computer components. The present invention provides a method which enables an optical wave guide to be produced quickly and accurately and which enables wave guide devices to be constructed without the assembly and connection problems encountered with the current technology.

DISCLOSURE OF THE INVENTION

According to the invention there is provided a method of producing an optical wave guide comprising projecting electromagnetic or ultrasonic energy into a concentrated energy zone in a body of a polymerisable material to cause polymerisation of that material at said zone by absorption of part of said energy and causing relative movement between said body of material and the projected energy so as to cause said concentrated zone to move in a path through said body and thereby produce a strand of polymerised material extending along said path, which strand is of higher refractive index than the surrounding body of material and is capable of acting as an optic wave guide for transmission of light along said strand.

Preferably said material is photopolymerisable and said energy is electromagnetic energy which is focused into said zone. More particularly, the wave guide may be fabricated as a transparent strand in a liquid, semi-liquid, gel or partially polymerised block of a plastic monomer by photopolymerisation at the focal region (Gaussian waist area) of one or more high power laser beams using a high NA (numeral aperture) lens.

The invention also provides a method of producing an optical wave guide device, comprising forming within a body of polymerisable material a plurality of wave guides each produced by the above defined method so as to form wave guide interconnections between a plurality of optic terminals disposed at spaced locations on said body.

The invention further provides an optical wave guide device comprising:

a body of a polymerisable material;

a plurality of optic terminals disposed at spaced locations on said body; and

a plurality of optic wave guides making wave guide interconnections between the terminals, each wave guide comprising a polymerised strand of said material of higher refractive index than the surrounding body of material.

A pair of said wave guides may be interconnected within said body so as to be capable of acting as an optical coupler for coupling light signals in those wave guides.

Alternatively, or in addition, the wave guides may be arranged in a three dimensional network in which some wave guides cross other wave guides with spatial separation between the crossing wave guides and without optical connection between them.

BRIEF DESCRIPTION OF DRAWINGS

In order that the invention and its various applications may be more fully explained, some specific examples will be described in some detail with reference to the accompanying drawings, in which:

Figure 1 illustrates one form of apparatus for carrying out a method in accordance with the invention in

order to produce an optical wave guide device;

Figure 2 illustrates a modification of the apparatus illustrated in Figure 1;

Figure 3 illustrates an optical coupler device produced in accordance with the invention;

Figure 4 illustrates a further type of wave guide device produced in accordance with the invention;

Figure 5 illustrates a wave guide device providing optical interconnections between fibre cores and opto-electronic components on an integrated circuit chip;

Figures 6 and 7 illustrate an electrically switchable optic coupler constructed in accordance with the invention;

Figure 8 illustrates a modification to the coupler illustrated in Figures 6 and 7;

Figures 9 and 10 illustrate an alternative form of an electrically switchable coupler constructed in accordance with the invention;

Figure 11 illustrates a modification to the switch illustrated in Figures 9 and 10; and

Figures 12 and 13 illustrate an optronically switchable coupler constructed in accordance with the invention.

BEST MODES OF CARRYING OUT THE INVENTION

In the apparatus illustrated in Figure 1, a high power laser 11 produces a TEM 00 laser beam 12 which is concentrated or focused by a lens system comprising a high numerical aperture lens 14 into a high energy concentration or focal region 15 within a body 16 of a photopolymerisable material which is supported on a table 17 of the apparatus. Table 17 is translatable in three orthogonal directions as indicated by the arrows 18, 19, 20 so that the body of polymerisable material 16 can be moved accurately in any direction in three dimensional space. The table 17 and mechanism for moving it may be precisely the same as in commercially available microscope stages in which movements in the three orthogonal directions are produced by stepping motors under computer control.

Body 16 of polymerisable material may be a thixotropic material or a gel or a partially polymerised

plastic mass contained in a casing 21. Movement of this body by translation of table 17 will cause the focal zone (Gaussian waist area) of the focused laser beam to move in a path through body 16 to produce photopolymerisation of the material along that path to generate a transparent polymerised strand. The polymerisation of most monomers produces shrinkage and an increase of the refractive index of the material, thus causing the polymerised strand to be capable of acting as an optical wave guide.

The polymerisation is preferably produced by two photon interaction with the monomer or with an activating catalyst substance mixed with the monomer so that the polymerised strand is produced at the locus of the moving focal point without the initiation of polymerisation in the cone of light on either side of the focus. More particularly, the reliance of two photon absorption in this way makes initiation of the polymerisation energy sensitive so that a threshold energy must be exceeded to initiate the polymerisation, thus suppressing unwanted polymerisation around the concentrated energy zone around the focus point of the laser.

The activation of molecular species leading to the required polymerisation may be due to the absorption of two photons of the same energy as described in the paper by Denk et al entitled TWO PHOTON LASER SCANNING FLUORESCENCE MICROSCOPY in the journal "SCIENCE", April, 1990. Alternatively, the polymerisation process may be activated by the simultaneous absorption of two photons of different colour in which the combined laser photon energy is tuned to the specific activation energy required for the initiating substance. Optical interaction of this type is described in the book entitled THEORY AND PRACTICE OF CONFOCAL SCANNING MICROSCOPY by Wilson & Sheppard published by Pergamon Press (see page 208 of First edition) and has a much higher quantum efficiency than the first method mentioned above. In both instances, and in other possible cases of multiple photon interaction, the result of the non-linear activation is that the probability of the required interaction between photons is highest at the focus and drops off very sharply away from the focus.

Polymerisation efficiency is highest if the laser is tuned to the activation energy of the photopolymerisation activation molecule. This is best achieved by means of a tuneable high power laser but may also be carried out by the focusing of two separate wavelength lasers at the same point in space. If these are pulsed lasers then it is also necessary that the pulses arrive simultaneously at the point.

Because of the highly non-linear photon activation, almost all of the polymerisation will take place at or near the focal point. This focal point may be located well within the liquid without concern that polymerisation will take place in the cone of light above or below the focus. If the focal point is traversed through the monomer it will generate a strand of polymer and it is possible to connect devices or desired points by a smoothly curved strand which will act as an optic wave guide between them. By starting the polymer strand at any desired point an optical connection can be made to any other design point. A high density optical wave guide network can thus be built up in three dimensions by generating strands which cross one another but which maintain spatial separation at the cross over regions to avoid optical interconnections. This may be achieved by moving the laser focus with a darning or weaving motion so that the strands are interwoven with spatial separation between them.

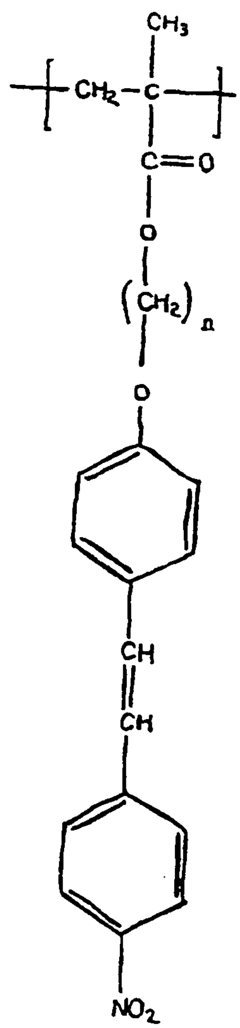
In the case of a simple isotropic waveguide the matrix material may contain any one of a variety of monomer materials such as styrene or styrene derivatives. A commonly used photo-initiation for this and for other plastics is azo di-iso butyro nitrile which operates by the formation of free radicals when a molecule of the substance absorbs a photon or photons of appropriate energy.

More commonly, epoxy materials are used in commercially available photo cured resins and a wide variety of other polymer materials can be activated by azo di-iso butyro nitrile and similar compounds.

It is desirable to increase the efficiency of upconversion of the photon energy to shorter wavelengths to

increase the rate of polymerisation. To achieve this end substances such as finely divided rare earth glasses can be incorporated in the polymer matrix.

In order to produce a highly non-centrosymmetric cross-section in the waveguide it is necessary to incorporate molecules of very high di pole moment such as



as present in polymer chain. These can be co-polymerised with a host of other monomers.

To assist the poling process and to make it more uniform it is desirable to incorporate substances such as

poly·vinyl carbazole as organic charge transfer agents.

A particularly effective combination uses DEH as an organic photo conductor in an organic photo conductor in an epoxy formulation called NNDN-NAN.

The polymerisation of the optic wave guide strand may also be initiated by the heating effect at the focus. In this case, it would be possible to initiate the polymerisation by producing a concentrated zone of ultrasonic sound energy rather than electromagnetic energy to produce polymerisation at the focus by heating or other effects generated by the sound waves. This could be achieved by the use of a piezo electric ultrasonic generator of the type used in ultrasonic microscopy.

In some cases, such as in the production of simple optical couplers, the optical wave guide strand may be produced by single photon activation. In this case, however, the packing density of the optical wave guide strands is limited because of excessive polymerisation outside the focal plane.

If a normal air lens is used to focus through a thickness of the monomer material, then spherical aberration will occur at focused depths above and below the optimum focal plane for the lens. If two separate wave lengths for photopolymerisation are used with such a lens the foci for the diffraction limited spots of the two colours will also only coincide for one specific depth of material (i.e. one correct achromatic plane). In both cases the cross-section of a polymerised optical strand will change as the strand changes in the depth below the surface at which the photopolymerisation took place. This problem can be eliminated by putting the monomer mass in a liquid of optical properties similar to those of the monomer and using an immersion lens. An alternative is to use a modified apparatus as illustrated in Figure 2 which avoids the need to immerse the monomer mass 16.

The apparatus illustrated in Figure 2 is a modification of that illustrated in Figure 1 and like components have been identified by like numerals. In this case the lens 13 and 14 are mounted in a barrel 31 which dips into a body of a liquid 32 held in a container 33.

The liquid 32 has optical properties similar to those of the body of polymerisable material 16 and container 33 is transparent. In this case, movement of the focal point 15 within the body is achieved by horizontal movements of table 17 in the orthogonal directions indicated by arrows 18, 19 and by vertical movements of barrel 31 as indicated by arrow 20A. This ensures that the effective optical path from the lens 14 to the focal point 15 remains the same regardless of vertical movement of the focal point. Any increase or reduction of the depth traversed within the body 16 is compensated by a corresponding decrease or increase in the depth of liquid 31 traversed by the focused beam.

The polymerisable material in which a wave guide is to be produced in accordance with the invention may be a partially polymerised solid plastic material in which further polymerisation is initiated by the photopolymerisation process to form appropriate wave guide strands. This is particularly advantageous in the production of optical couplers and an example of an optical coupler made in this way is illustrated in Figure 3.

The optical coupler illustrated in Figure 3 comprises a body of partially polymerised plastics material 41 disposed within a protective casing 42. The ends of four optical fibres 43, 44, 45, 46 are embedded in the partially polymerised block 41. The embedded fibre tips may be pre-tapered either by etching with acid fluoride solutions or by melting and drawing. The four embedded ends are linked together by traversing a focused laser spot through the partially polymerised matrix and thus forming strands of more highly cross-linked material in the polymer. In the configuration illustrated in Figure 3, these strands 47, 48, 49, 50 are connected to the embedded ends of the fibres and interconnect with one another in the region 51 to form a coupler waist area in which coupling of signals can take place. For example fibres 43 and 44 may be input legs of the coupler and fibres 45 and 46 the output legs. The split ratio of the coupler can be controlled if during the fabrication process light is ejected from a laser 52 into one of the input legs and the

outputs in fibres 45, 46 are monitored by photo detectors 53, 54. It is also possible to tune the characteristics of the coupler or other device by means of temperature variation as may be produced by a neighbouring Peltier effect by passing an electric current through a device or even a resistive wire close to the active region of the device.

Photopolymerisation of further sections of the plastic block material could be effected to induce shrinkage and stress in the polymerised strands and thus introduce birefringence and polarisation specificity. It is thus possible to produce an optical bifurcation or coupler which splits the light in the two output legs in mutually orthogonal polarisation planes.

In practice during fabrication, if an operator focuses each of the two points to be interconnected by a wave guide onto an eyepiece cross hair and data logs their X, Y and Z coordinates and also programs the initial directions for the wave guides then a computer can calculate the optimum curve for a strand linking the two points and automatically track the locus of the focused beam along the appropriate path using the mechanical stage driven by the controlled stepper motors. The computer memory can also ensure that threads do not intersect or come close enough to produce cross-talk or alternatively it can deliberately generate couplers and other optical devices by running wave guide sections close and parallel to one another. The manufacturing process is done in a point to point sweep similar to the way that gold wires are joined from header pins to integrated circuit chip edges.

Figure 4 illustrates a coupler similar to that illustrated in Figure 3 but modified by the addition of a squeezing mechanism so that the characteristics of the coupler may be tuned by a variable squeezing action on the device. The coupler comprises a plastic block 61 disposed between upper and lower glass sheets 62, 63 and end sheets 64, 65. It has input fibres 66 and output fibres 67 interconnected by photopolymerised cross-linked strands 68 within the body of plastic. The interconnection may be similar to that made in the device illustrated in Figure 3.

The characteristics of the coupler are tuned by varying pressure applied between a pair of anvils 69, 70, which may be mounted on the ends of squeezer calliper arms or in any other appropriate squeezing mechanism.

Figure 5 illustrates a wave guide device 71 constructed in accordance with the invention and making optical interconnections between three optical fibres 72, 73, 74 and opto-electronic components 75, 76, 77, 78 on an integrated circuit chip 79. Device 71 may comprise a solid block 81 of partially polymerised plastic material with photopolymerised strands 82 formed in the block to make appropriate interconnections.

It is possible to fabricate a wide variety of wave guide devices by the method of the present invention. For example, in line interference filters may be produced by a strand having a section in which a series of uniformly spaced microscopic "beads" of polymer have been produced.

It is also possible to generate strands of asymmetric cross-section by either modifying the aperture of the focusing lens during the formation process or making short fast scanning movements at right angles to the slower movement generating the polymerised strand. Such an asymmetric cross-section can be made to produce an optic wave guide that will support only one polarisation mode or will maintain polarisation. For example, a Y splitter can be fabricated by making a strand of circular cross-section up to a certain point and then by continuing the polymerisation into two branches of the Y. The branches are made to separate the two polarisation states of the light split between them by fabricating them so that the long axes of symmetry of their cross-sections are mutually orthogonal.

It is undesirable that further polymerisation of the matrix takes place after a wave guide device has been fabricated as this might result in shrinkage and pulling away of the optical connecting strands from the devices to which they are attached. To avoid post fabrication polymerisation, the photo-activated catalyst can be chosen so that it readily breaks down within a few days or the materials may be chosen so that the polymerisation takes

place only at an elevated temperature. Alternatively, an amount of polymerisation inhibitor may be added to the fabricated network cell before sealing so that it can diffuse through the matrix and maintain a thixotropic gel state or to make it more viscous or to convert it into a rubbery gel. It is possible to produce polymer strands which are quite strong and elastic .

The present invention makes possible the production of active optical devices made from poled (electret) optic wave guide strands. A poled wave guide strand can be produced in accordance with the invention by carrying out the photo-induced polymerisation of the strand within an electric field to produce charge separation across the strand in cross-section. This charge separation remains after the electric field is removed to produce a wave guide is an "electret" and is highly non-centrosymmetric in cross-section. If two wave guide strands run close together and parallel to one another they act as a coupler for light energy. If the two adjacent sections of wave guide strand have opposite electrical polarity in cross-section, then the coupling ratio between them can be varied by the application of an electric field, for example through application of a potential difference between electrodes embedded in the plastic matrix. Figures 6, 7 and 8 illustrate such electrically switchable couplers.

The coupler illustrated in Figures 6 and 7 comprises a block 84 of polymerisable material within which a pair of optical wave guide strands 85, 86 are formed by photo-induced polymerisation in accordance with the present invention. Strands 85, 86 extend from one pair of optic terminals 87, 88 in an end face 89 of the block 84 to a second pair of optic terminals 91, 92 in an opposite end face 93 of the block. In the interior of the block, strands 85, 86 come close together so that mid-sections 94, 95 of the strands extend in close parallel relation to one another. These mid-sections of the strands are disposed between a pair of plate electrodes 96, 97 embedded in the block 84 of polymerisable material and connected to wires 98, 99 extending outside the block for application of

potential difference between the electrodes.

During polymerisation of the strand 85 a potential difference is applied between the two electrodes such that electrode 96 has negative polarity and electrode 97 positive polarity. This causes a charge separation across the strand 85 in cross-section with the polarity indicated in Figures 6 and 7. During polymerisation of strand 86 a potential difference is applied between the electrodes with reverse polarity to result in a charge separation across strand 86 in cross-section of opposite polarity to the charge separation in strand 85 as also indicated in Figures 6 and 7. The device is operable as an electrically switchable coupler since the coupling ratio between the two strands can be varied by the application of a potential difference between the electrodes 96, 97 during operation of the device.

Figure 8 illustrates a modification to the switchable coupler construction in which the two wave guide strands 85, 86 are disposed one above the other between the two electrodes rather than side by side. In these constructions the electrodes may be fabricated from a transparent conductor material such as indium tin oxide on glass. The electric field applied during the photo-induced polymerisation process need not necessarily be applied through these electrodes but could be induced by electrodes or some other means external to the block 84. The applied electric field can be varied during the polymeristaion process so as to produce a strand with alternately oppositely polarised or charged sections. Such a strand will function as a frequency doubler and a parametric amplifier.

In such applications the successively reversed optic waveguide sections must be of a very specific length.

This length corresponds to the distance over which the pump wave and the wave to be amplified or frequency doubled maintain the correct phase relationship for the desire energy transfer to take place.

As the wave travels along the waveguide by the distance at which the two waves go out of phase then the polarity of the waveguide cross-section must be reversed so

that energy will still continue to be transferred to the wave to be amplified or frequency doubled from the pump or fundamental wave.

In such devices feedback controlled mechanisms must be included to tune the optic waveguide so that the two waves do not get out of step as they pass along the waveguide. Such tuning mechanisms may include temperature control, the application of a potential difference between electrodes on either side of the optic waveguide strand or control by means of pressure applied to the waveguide.

Figures 9 and 10 illustrate an electrically switchable wave guide device similar to that illustrated in Figures 6 and 7 but incorporating a central non-poled wave guide strand between the two poled strands. The central non-poled strand is identified by the numeral 101. The other components are all identical to those of the device illustrated in Figures 6 and 7 and have been identified by the same numerals. The device illustrated in Figures 9 and 10 can be operated as an optic switch in which light in the central wave guide strand 101 can be switched between the two outer poled wave guides 85, 86 by changes in potential between the electrodes 96, 97. Figure 11 illustrates an alternative arrangement of the adjacent sections of the three wave guide strands between the electrodes along the same lines of the modification illustrated in Figure 8.

The present invention also enables the fabrication of couplers which are optronically switchable. This can be achieved by including in the polymerisable material finely divided colloidal or cluster groups of semi-conductor materials such as CdS and CdSe. These materials may be dispersed throughout the polymerisable material or concentrated in the area where optronic switching is to be achieved. The photogeneration of electron hole pairs in the semi-conductor materials shift the sharp spectral edge cut-off wave length of the material such that light impinging on the material can change the transmission of a light beam within the material. The production of optical fibre and fused bi-conical taper couplers using glass containing such materials has not been successful, since the edge band cut-off wave length spreads

out too much. However, it is possible to fabricate wave guides in plastics containing these materials using two photon-initiated polymerisation effects at the focus of an intense laser beam in accordance with the invention as previously described. This fabrication cannot be carried out with blue or ultraviolet light normally used for photopolymerisation because of the high optical density of such materials at shorter wave lengths.

A coupler consisting of two parallel closely spaced wave guide strands containing finely divided semi-conductor material can thus be made to act as an optical switch in which the coupling ratio between the strands can be altered by the external application of light. By the provision of a third parallel wave guide strand sufficiently close to evanescently interact with one or both of the coupler sections it is possible to produce a coupler which is optronically switchable because of changes in the refractive index of the surrounding material due to formation of the electron hole pairs in the semi-conductor particles. Thus, the coupler interaction is changed and switching takes place between the output legs of the coupler. Such a coupler is illustrated in Figures 12 and 13.

The coupler illustrated in Figures 12 and 13 comprises a block 110 of polymerisable plastics material containing finely divided semi-conductor material such as CdS or CdSe. Three polymerised wave guide strands 111, 112, 113 are formed in the block 110 with their mid-sections extending in close parallel relation. By the mechanism described above, the coupling ratio between the wave guides 112, 113 can be altered by the passage of light through the other wave guide 111.

Intensity dependent optical bistability in a normal coupler configuration will also take place in four port couplers fabricated in these materials by the methods described.

CLAIMS

1. A method of producing an optical wave guide comprising projecting electromagnetic or ultrasonic energy into a concentrated energy zone in a body of a polymerisable material to cause polymerisation of that material at said zone by absorption of part of said energy and causing relative movement between said body of material and the projected energy so as to cause said concentrated zone to move in a path through said body and thereby produce a strand of polymerised material extending along said path, which strand is of higher refractive index than the surrounding body of material and is capable of acting as an optic wave guide for transmission of light along said strand.

2. A method as claimed in claim 1, wherein said material is photopolymerisable and said energy is electromagnetic energy which is focused into said zone.

3. A method as claimed in claim 2, wherein said projected energy is a light beam produced by a laser.

4. A method as claimed in claim 2 or claim 3, wherein said energy is focused so as to shape said zone in such a manner that the strand is a symmetrical cross-section.

5. A method as claimed in any one of claims 2 to 4 wherein the polymerisable material is photopolymerisable by two photon absorption process.

6. A method as claimed in claim 5, wherein said polymerisable material is a thixotropic gel.

7. A method as claimed in any one of claims 2 to 6, wherein the polymerisable material is a partially polymerised gel.

8. A method as claimed in any one of claim 2 to 7, wherein photo-induced polymerisation of said material is effected adjacent a segment of said strand so as to produce stress induced birefringence of that section.

9. A method as claimed in any one of claims 2 to 8, wherein the photo-induced polymerisation of said strand is carried out within an applied electric field to produce charge separation across the strand in cross-section

whereby the strand is non-centrosymmetric in cross-section.

10. A method as claimed in claim 9, wherein the electric field is applied by application of an electrical potential difference between a pair of electrodes embedded in polymerisable material.

11. A method as claimed in any one of claims 2 to 9, wherein the photo-induced polymerisation of said strand is carried out within a varying electric field to form the strand with alternately oppositely polarised or charged sections.

12. A method as claimed in claim 11, wherein the varying electric field is applied by applying a varying electric potential difference between a pair of electrodes embedded in the polymerisable material.

13. A method as claimed in any one of claims 2 to 9, wherein the strand is formed with regions of enlarged cross-sections at intervals along its length.

14. A method as claimed in claim 12, wherein said enlarged cross-sections are spaced at regular intervals along the strand.

15. A method as claimed in any one of claims 2 to 8, wherein the body of polymerisable material contains finely divided semi-conductor material.

16. A method of producing an optical wave guide device, comprising forming within a body of polymerisable material a plurality of wave guides each by a method of any one of the proceeding claims so as to form wave guide interconnections between a plurality of optic terminals disposed at spaced locations on said body.

17. A method as claimed in claim 16, wherein a pair of said wave guides are interconnected within said body so as to be capable of acting as an optical coupler for coupling of light signals in those wave guides.

18. A method as claimed in claim 16, wherein said plurality of wave guides are formed to produce a three dimensional network of wave guides in which some wave guides cross other wave guides without optical interconnection by maintaining spatial separation between the crossing wave guides.

19. A method as claimed in claim 16, wherein said

plurality of wave guides comprises a pair of adjacent strands produced by photo-induced polymerisation carried out within differing applied electric fields whereby to produce differing charge separations in the adjacent strands such that optical coupling between the strands can be varied by variation of an applied external electric field.

20. An optical wave guide device, comprising:

a body of a polymerisable material;

a plurality of optic terminals disposed at spaced locations on said body; and

a plurality of optic wave guides making wave guide interconnections between the terminals, each wave guide comprising a polymerised strand of said material of higher refractive index than the surrounding body of material.

21. An optical wave guide device as claimed in claim 20, wherein said polymerisable material is a partially polymerised plastics material.

22. An optical wave guide device as claimed in claim 20 or claim 21, wherein said polymerisable material is a thixotropic gel.

23. An optical wave guide device as claimed in any one of claims 20 to 22, wherein a pair of said wave guides are interconnected within said body so as to be capable of acting as an optical coupler for coupling light signals between those wave guides.

24. An optical wave guide device as claimed in any one of claims 20 to 22, wherein said wave guides are arranged in a three dimensional network in which some wave guides cross other wave guides with spatial separation between the crossing wave guides and without optical connection between them.

25. An optical wave guide device as claimed in any one of claims 20 to 22, wherein sections of said plurality of waveguides extend adjacent one another between a pair of electrodes embedded within said body and at least one of said sections has electrical charge separation across it, whereby optical coupling between said sections can be varied by varying application of a potential difference

between the electrodes.

26. An optical wave guide device as claimed in claim 25, wherein a pair of said strand sections have charge separation of mutually opposite polarity.

27. An optical wave guide device as claimed in any one of claims 20 to 22, wherein sections of said plurality of waveguides extend adjacent one another and the material of said body surrounding those sections contains finely divided semi-conductor material whereby optical coupling between said sections can be varied by application of light to the device.

28. An optical wave guide device as claimed in claim 27, wherein there are three of said strands and optical coupling between two of those strands can be varied by application of light to the third strand.

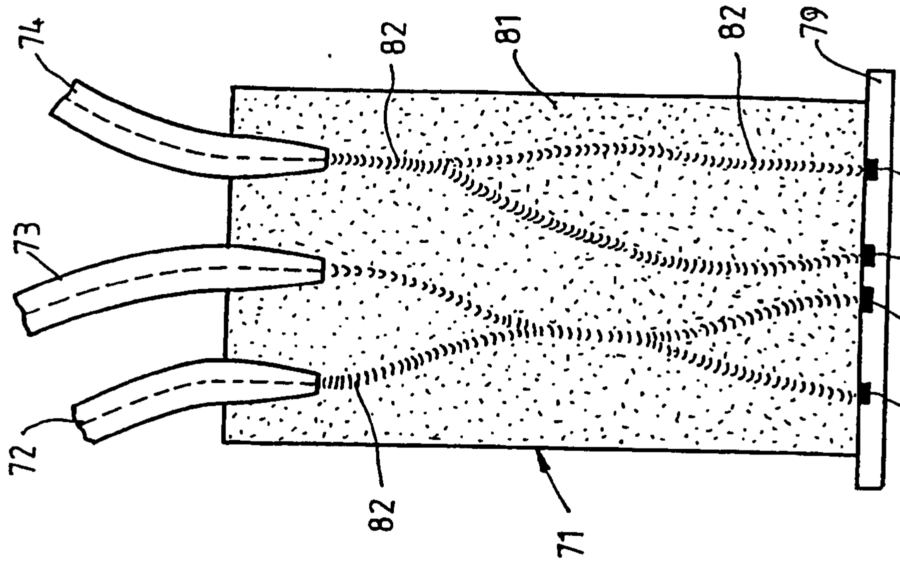


FIG. 5.

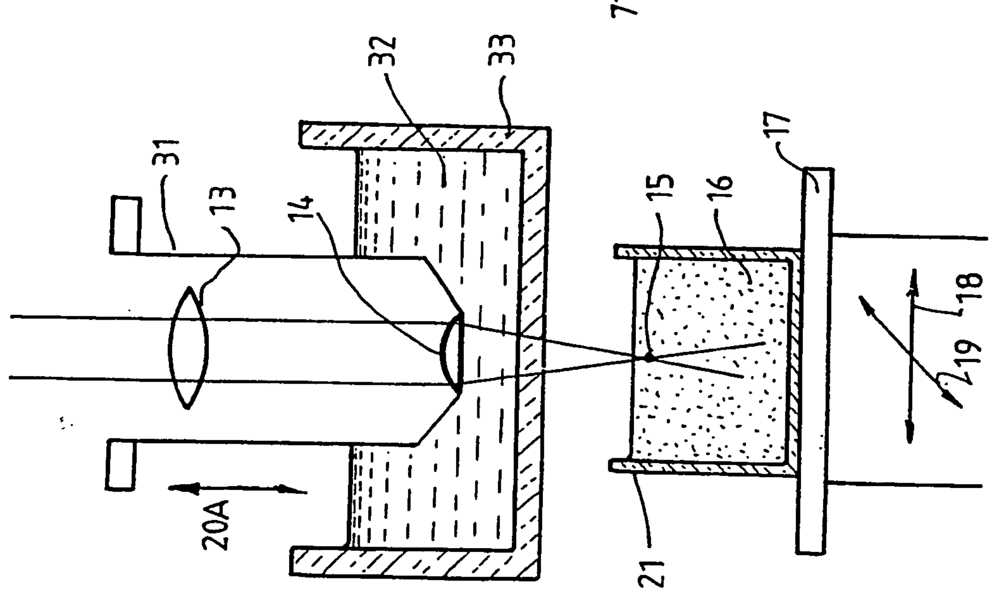


FIG. 2.

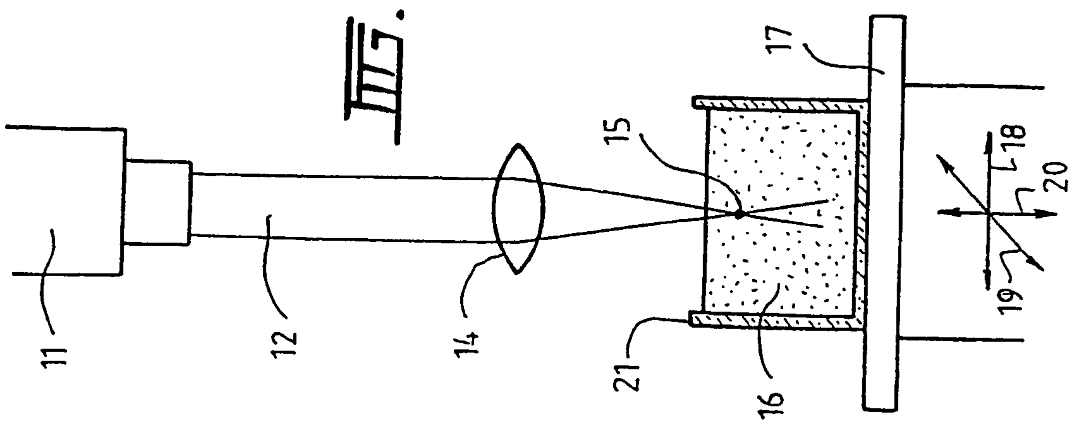


FIG. 1.

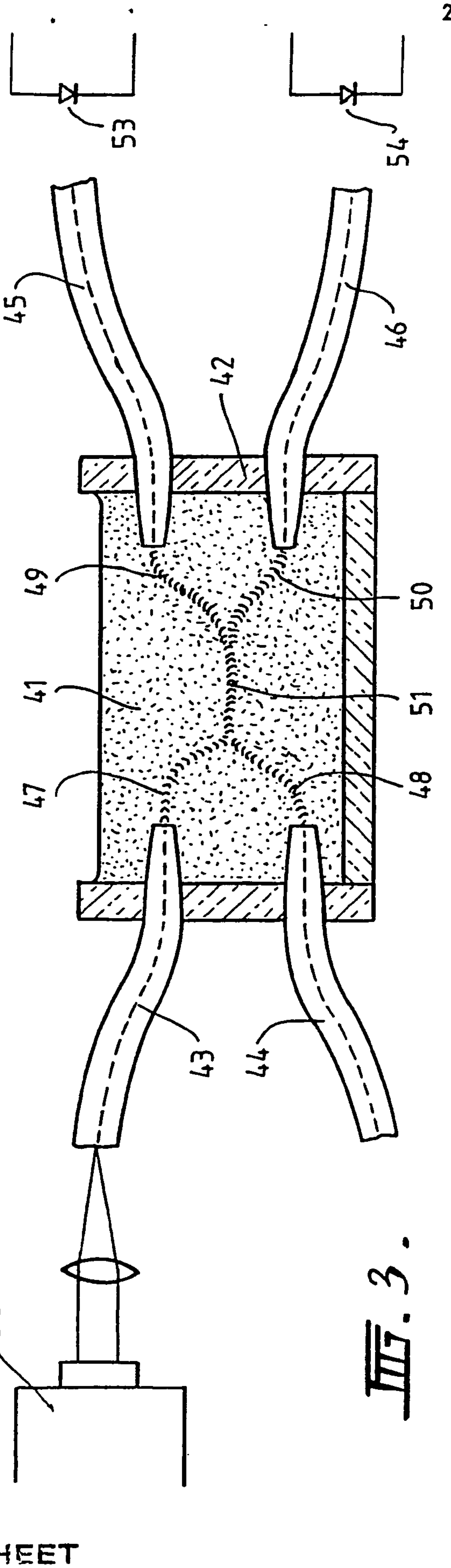


FIG. 3.

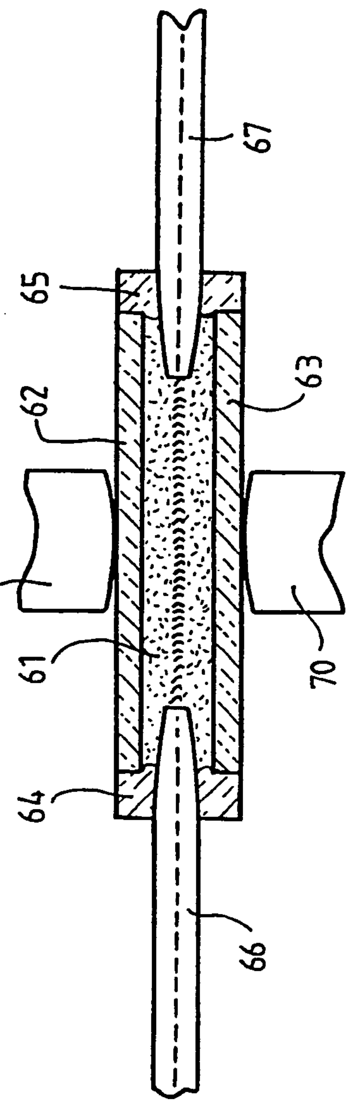


FIG. 4.

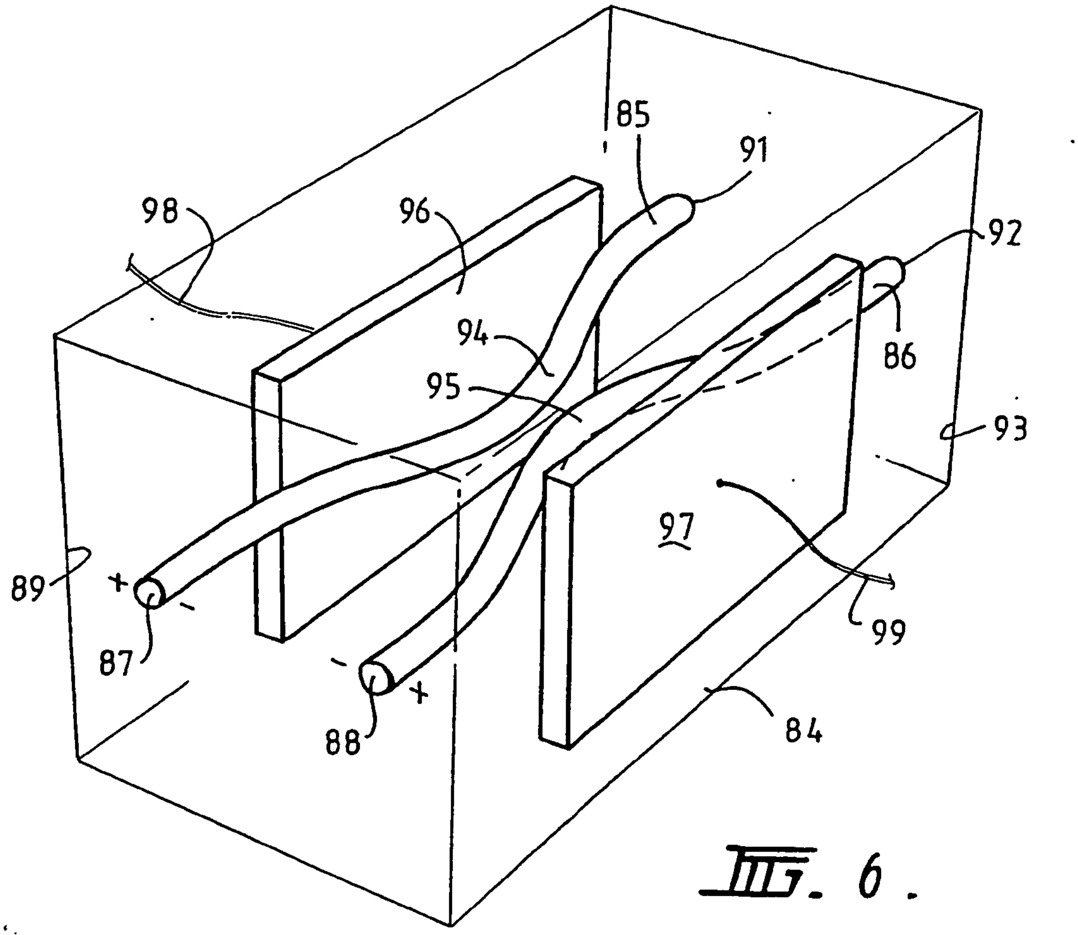


FIG. 6.

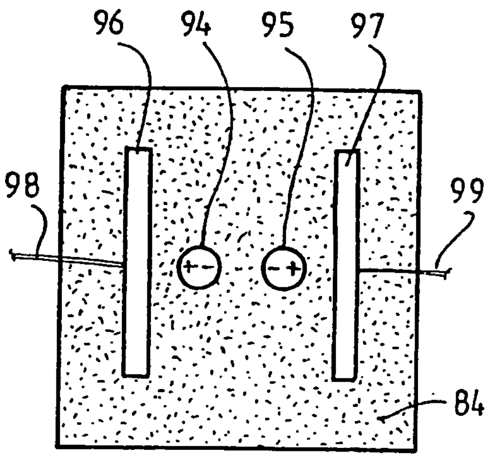


FIG. 7.

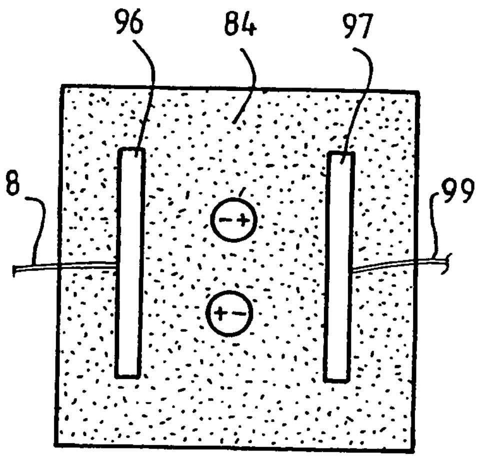


FIG. 8.

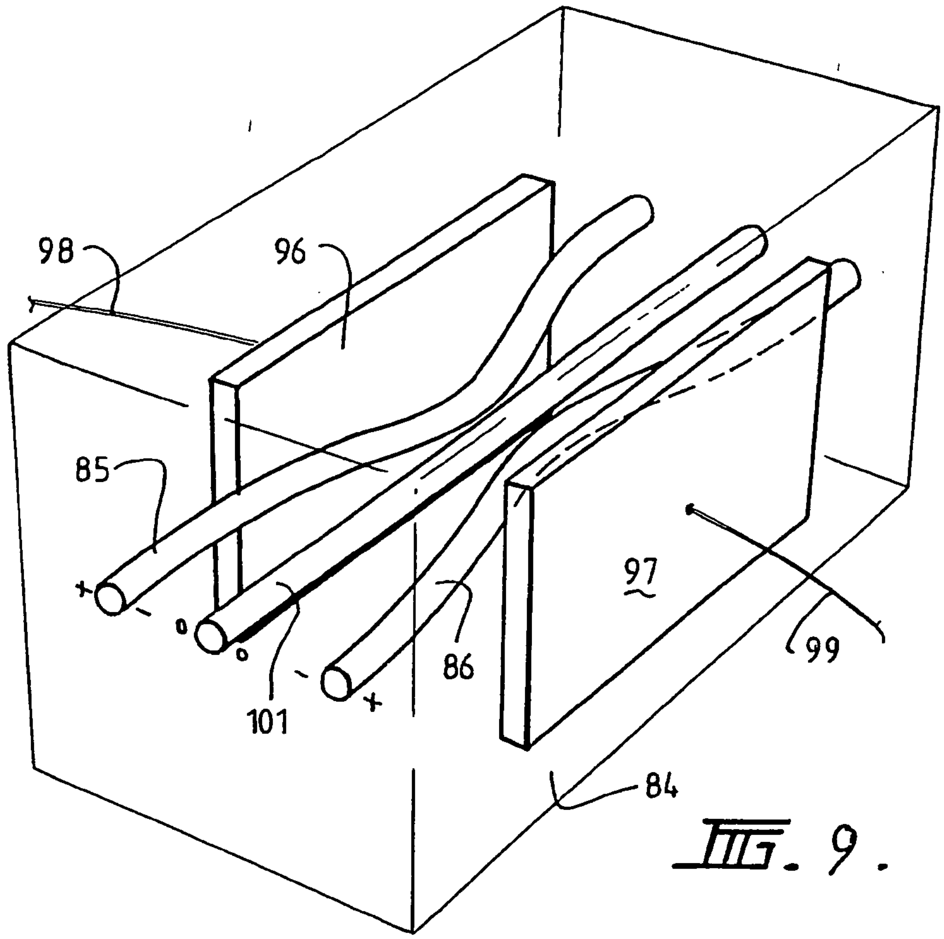


FIG. 9.

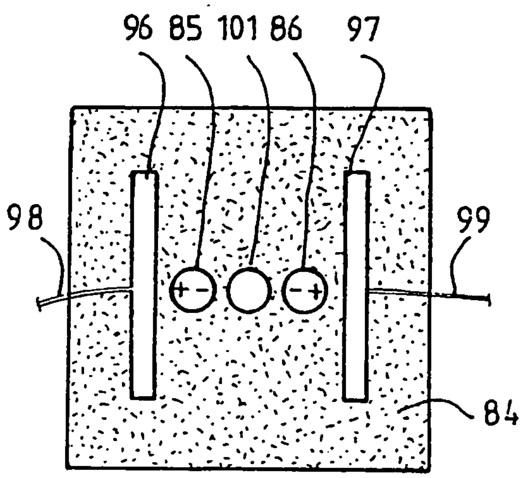


FIG. 10.

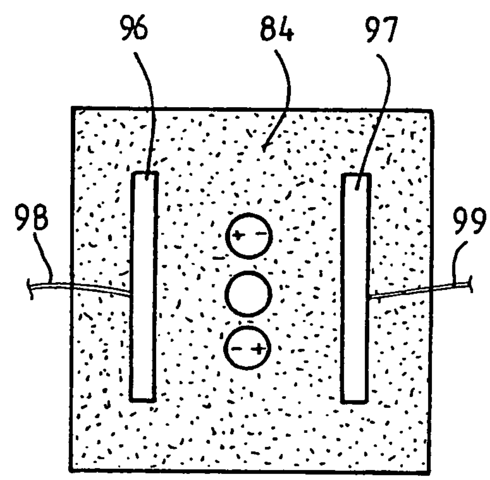


FIG. 11.

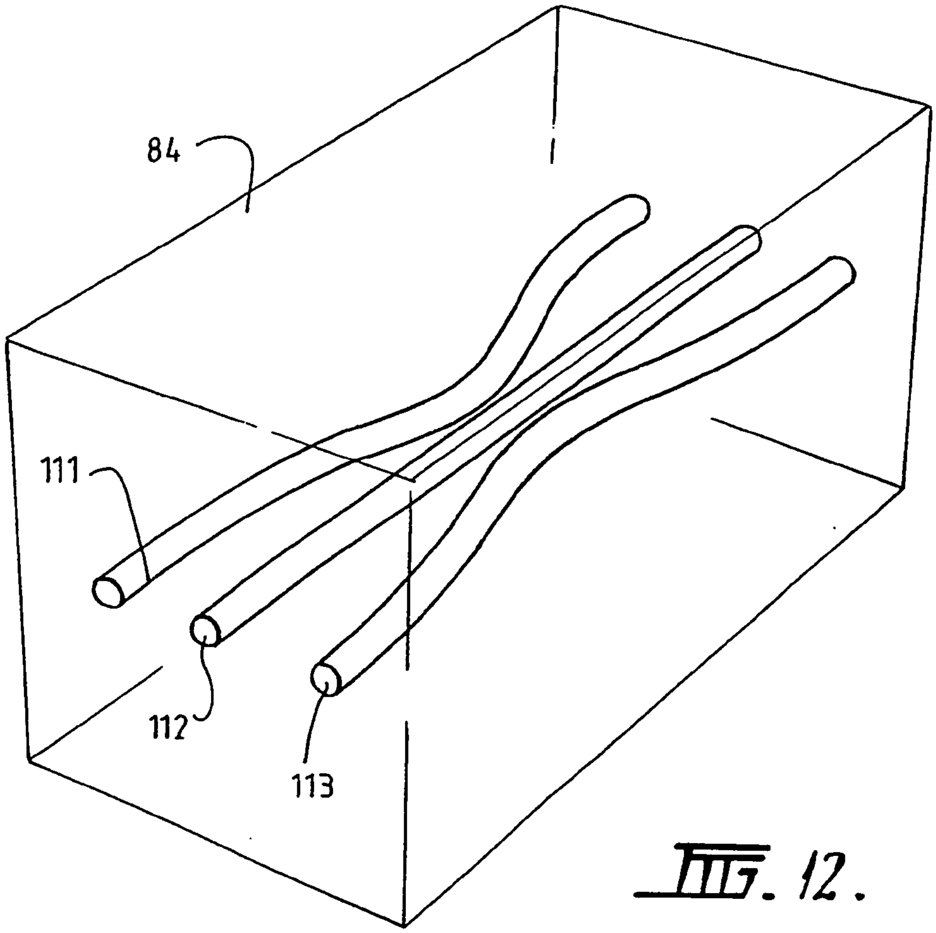


FIG. 12.

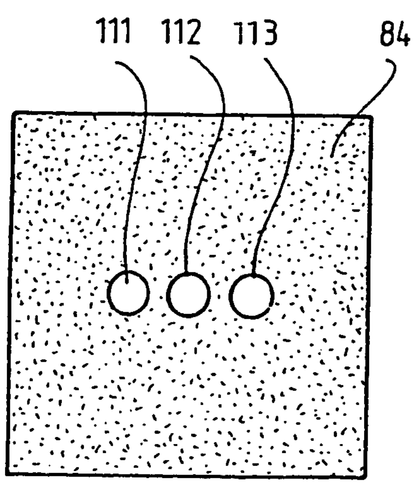


FIG. 13.

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent classification (IPC) or to both National Classification and IPC
Int. Cl.[5] B29D 11/00, G02B 6/10, 5/172, B29C 35/08 // B29 L 11/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	B29D 11/00, G02B 6/10, 5/172, B29C 35/08 // B29L 11/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

AU : IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category*	Citation of Document, [11] with indication, where appropriate of the relevant passages [12]	Relevant to Claim No [13]
A	EP,A,372885 (HERIOT-WATT UNIVERSITY) 13 June 1990 (13.06.90) See claim 1.	(1,20)
A	EP,A,131058 (MITSUBISHI RAYON CO. LTD.) 16 January 1985 (16.01.85) See whole document.	(1,20)
A	EP,A,351211 (BT & D TECHNOLOGIES LIMITED) 17 January 1990 (17.01.90) See claims 1, 2, 7.	(1,20)
P,A	US,A,4988274 (KENMOCHI) 29 January 1991 (29.01.91) See column 2, lines 31-47.	(1)
A	Patents Abstracts of Japan, M-698, page 23, JP,A,62-280006 (MATSUSHITA ELECTRIC IND CO LTD) 4 December 1987 (04.12.87)	(1)
A	AU,A,33732/89 (HOECHSTAKTIENGESELLSCHAFT) 2 November 1989 (02.11.89) See claims 1 and 8.	(1,20)

* Special categories of cited documents : [10]

"A" Document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior t the international filing date but later than the priority date claimed

"T" Later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
17 September 1991 (17.09.91)	8 October 91
International Searching Authority	Signature of Authorized Officer
AUSTRALIAN PATENT OFFICE	J. P. ELIJAH J. P. Elijah

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim numbers , because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim numbers , because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4a

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

Claim 1 is directed to a method by which electromagnetic or ultrasonic energy is concentrated at an energy zone in a body of polymerisable material at a specific point/points, under movement, to manufacture optical wave guides. Claim 20 is not so restricted as the product of claim 1 could be made by other techniques, such as co-extrusion, spinning. Claim 20 does not clearly relate to the inventive concept of the method defined in claim 1.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☒ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL APPLICATION NO. PCT/AU 91/00267

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Member	
EP 131058	DE 3375520	
EP 351211	AU 39764/89	WO 9000753
EP 372885	CA 2004433	JP 2271853
	US 5031980	
US 4988274	EP 322353	JP 1163027
AU A89 33732	CN 1037402	DE 3814296
	EP 340557	JP 1314206
	US 4979799	

END OF ANNEX